Perspective on Status of APS Microprobe in 2013

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This is an effort to provide a general perspective; the classifications listed below are therefore somewhat arbitrary, and are not meant to provide a complete list.

A) Status - Summary

The Advanced Photon Source has worldwide renown strength in micro- and nanoprobe techniques and applications. Significant capabilities exist in the following areas:

1) Microprobe work at moderate spatial resolution (> 0.25 μm).
   - Techniques:
     - X-ray fluorescence mapping, X-ray fluorescence spectroscopy
     - X-ray diffraction
     - Combination with techniques such as inelastic scattering, high pressure, magnetic contrast etc
   - Main scientific areas:
     - Environmental/Geo science
     - Materials science
   - High-resolution Optics: mainly KB systems, some refractive lens and diffractive optics
   - Strength:
     - Non-dispersive focusing
     - High flux/large throughput. Makes use of APS *flux*
     - Good flux at high energies (> 30 keV)

2) Microscopy/Nanoprobe with spatial resolution of 0.25μm
   - Techniques:
     - X-ray fluorescence mapping, X-ray fluorescence spectroscopy
     - X-ray diffraction
     - Coherent X-ray diffraction
   - Main scientific areas:
     - Biology, environmental science
     - Materials science, nanoscience, physics
   - High-resolution optics: mainly diffractive optics, some reflective optics, refractive optics
   - Strength: high spatial resolution; makes use of APS *coherent flux (i.e. brilliance).* Throughput is intrinsically limited by coherent flux

Almost all of the micro/Nanoprobe capabilities use x-rays with photon energies between 4 keV and 25 keV, with some important efforts at lower and higher energy.

Outside the area of micro/Nanoprobe, the APS has very significant and world-leading capabilities in development and fabrication of x-ray optics. The APS has a particular competence and leadership in both high-resolution reflective optics and high-resolution diffractive optics.

B) Future Potential

The APS is uniquely positioned to continue pushing the state of the art of its microprobe/ Nanoprobe programs and maintain worldwide leadership.

On the Microprobe level, high flux in small spots allows deployment of photon hungry methods such as fluorescence tomography. Also, higher-energy applications will continue to benefit from large flux. These developments can make use of x-ray optics, namely reflective optics that can be reasonably well fabricated.

On the Nanoprobe level, the APS is in a wordwide unique position to push towards a spatial resolution of 20 nm, possibly below, for hard x-ray energies from 10 keV and below to 30 keV (for higher energies, nanofocusing would be instrinsically limited by small coherent flux, coupled with small cross sections, and microprobe would become the more useful tool). Advancing into the spatial resolution range of below 30 nm will have the potential for large and unique scientific impact: cellular substructures at the level of can be accessed, nanoscale systems be studied at lengths scales that exhibit effects of confinement, and the elemental sensitivity of x-ray nanoprobes will improve into the range of individual nanoaparticles (less than 100 atoms, Zn, 10 keV).

While this author sees strong potential in the improvement of microprobes, the opportunity in the Nanoprobe range appears to be unique and timely. *Unique* in that the APS has worldclass expertise in all relevant technologies: (i) Optics R&D and Fabrication (ii) nanopositioning engineering and metrology (iii) scientific expertise in biology, medical sciences, materials science and nanoscience. *Timely* in that recent instrumentation progress makes sub-30 nm focusing feasible, and that a significant number of scientific applications in the fields mentioned above aggressively request higher spatial resolution,

In order to further strengthen the microprobe programs, in particular with view to throughput, and to make significant progress towards nanofocusing and its potential applications, investment into the following areas would be of significant importance:

1) Efficient, fast, large-solid angle detectors/detector geometries and (relatively low-maintenance) electronics to allow x-ray fluorescence mapping and spectroscopy at high fluorescence counts (e.g. 10 Mhz count rate at 150 eV resolution (Mn Ka)). This will e.g. enable fluorescence tomography in efficient microprobes as user tool by maximizing throughput, and both reduce radiation damage and increase throughput for Nanoprobe methods that must use coherent flux only.
2) Coupled with (1), development of efficient, fast data acquisitions schemes and related data buffering/storage systems.

3) Move towards good vacuum or clean He environment for reflective microfocusing optics. This will reduce contamination and increase (i) lifetime of microfocusing mirrors (ii) coherence preservation of nanofocusing mirrors.
4) Push towards 10 nm x-ray focusing optics for the 5 – 30 keV range, with a 5-year goal of a 2D resolution of 15 nm x 15 nm at good focusing efficiency
5) Increase nanoengineering capabilities. Mechanical engineering is only one leg of nanoengineering. To achieve control at the nanometer level, it must be coupled with metrology *and* proper controls implementation. Integration of advanced positioning concepts with sophisticated but stable metrology systems and related controls is required. This includes metrology capabilities that allow testing of advances positioning.controls systems. Close and effective collaboration across APS groups to create such a nanopositioning capability would appear to be a promising opportunity.
6) Cryo capabilities are required to reduce the effect of structural damage to samples in both biology and materials science. Radiation doses at the sub-30 nm resolution level approach and might exceed 10^{10} Gy, and LN2-based cryo techniques have been demonstrated both electron and x-ray microscopy to be effective up to the 10^{10} Gy level.